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Invited paper

Lotfi A. Zadeh: On the man and his work

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Abstract Zadeh is one of the most impressive thinkers of the current time. An engineer by formation, although the range of his scientific interests is very broad, this paper only refers to his work towards reaching computation, mimicking ordinary reasoning, expressed in natural language, namely, with the introduction of fuzzy sets, fuzzy logic, and soft computing, as well as more recently, computing with words and perceptions.

1. Introduction

Professor Zadeh is a person who produced and continues to produce important ideas that are influencing, and will continue to influence not only scientific and philosophical thought, but also technological development.

Nevertheless, I must confess that at the very moment of preparing this paper, I was tempted to courteously decline. I was conscious that I have no sufficient authority to talk about Zadeh, a scientist and engineer whose research production surpasses, by and large, any possibility of doing an appropriate presentation of the new ideas and new ways of seeing things, systems and processes that he has introduced since 1946.

But, at the end, it was a sense of friendship and respect for Lotfi Zadeh, shared with the full community of people working on Fuzzy Logic, that guided me to an affirmative and perhaps audacious resolution. I remembered what I wrote in 1985 in a Special Contribution to the International Symposium on Multiple-valued Logic, on the occasion of celebrating twenty-five years since Zadeh's first paper on fuzzy sets: "let us not forget that above and beyond the academic and the engineer is the man, whom we remember not only for his exceptional kindness and courtesy, but also especially for his unique sense of friendship". (All that appears in this paper under quotation marks, come from either the Reference section at the end, or from Zadeh's own words.)

I met Zadeh for the first time in a significative year for Fuzzy Set Theory. It was in 1977 in Barcelona, and the year was significant because of the publication of the paper "Fuzzy Sets as a Basis for a Theory of Possibility". We organized, that year, the *First Conference on Mathematics at the Service of Man*, and we invited Zadeh to deliver a plenary lecture; he lectured a version of that paper.

We invited Zadeh because earlier, in 1974, nine years after his paper on "Fuzzy Sets", I knew about the subject through an article in a French news-paper by Professor Arnold Kaufmann and, after some bibliographical searching, I got in touch with a, then, new theory which I immediately linked with some ideas of Karl Menger whose Probabilistic Metric Spaces I had been working on since 1964.

I remember that while listening to the lecture in Barcelona, a proverb by an old Chinese thinker came to mind: "What can I say on the Sea to the frog, if he never was out of his puddle?". I presumed, as it was, that to acquire credibility among scientists, especially logicians and mathematicians, would not be an easy task. And, in fact, it took more than 15 years after 1965.

Some characteristics of Zadeh's personality were an important part of his final success. He neither refused to discuss his ideas, nor tried to make a kind of academic lobby. He never tempted people to abandon their own ideas while of course discussing them, and he always recognized the utility of other methods different from fuzzy methods, when suitable. Even more, he approached people of all races, religions and countries, and today the community of researchers in fuzzy logic or those using fuzzy methods is spread all over the world.

Mainly, people were attracted by the nice ideas underlying the theory, and by the wish of having available some more

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flexible structures for a renewal of tools, in short. It is not to be forgotten that 1965 came just in the middle of the turbulent sixties; years in which many people were looking for fresh air and new creative attitudes.

In my case, I was first attracted by the old ideas of Fréchet and the more modern ones of Menger on Generalized Distances, partially as a reaction against the "bourbakization" of Mathematics I suffered during my studies at Barcelona University from 1958 to 1963. I felt an anti-structuralist tendency that was part of my interest in Zadeh's ideas; I have always had a tendency to work in Mathematics not too far from reality.

The acquaintance with Zadeh was for me a perfect complement to the acquaintance with Menger. Menger's was the work of a Mathematician, perhaps a genius, never disinterested by the problems of Philosophy, Logic, Economics, Physics, Ethics, etc., but he was a man of the thirties and forties. Zadeh's work is the work of an engineer in the age of Cybernetics, always interested in Mathematics and its application to System Sciences, Computer Sciences, Logic, Linguistics and Artificial Intelligence.

Essentially, to my understanding, Zadeh reestablished, at least in part, what for me should be a feature of logic, the analysis of human reasoning in the line of the great thinkers of the past, but using, as did Augustus De Morgan and George Boole, the formalism of Mathematics. Logic, after Peano and Russell, was at the foundation of mathematics; of course with a *corpus* of results that are part of the glory and honour of Mankind, but too far from the common processes of reasoning that, as George Pólya showed in his "Patterns of Plausible Inference", are very often used by scientists to obtain new results in Science and also in Mathematics.

I remember that in 1974, reading Zadeh, I found in his 1971 "Similarity Relations and Fuzzy Orderings" a paper that very much attracted my attention. Some references to books that influenced my studies on Generalized Distances are "Taxonomy", by Sokal and Sneath, "Functional Equations" by Aczél, "Linguistics" by Lyons and especially Watanabe's "Knowing and Guessing" in which lecture I was involved at that time.

Among other scientists, I have a deep feeling of gratitude both to Menger and Zadeh.

2. New subjects

Lotfi A. Zadeh was born in 1921 in Baku (Azerbaydzhan, former USSR) son of an Iranian press correspondent, and received a French-based education in Tehran, which, in his own words, was "very good, but traditional". At the age of thirteen he constructed a rotary motor that was "simpler than the Wankel motor engine". He graduated in 1942, at Tehran University, in Electrical Engineering and in 1944 entered M.I.T. where, two years later, he obtained a degree in Electrical Engineering. In 1946 he moved to Columbia University.

At Columbia University he was responsible for the then new subject: "Theory of Information and Network Analysis". In 1949, he was awarded a doctorate for his work on circuits and systems on frequency-domain analysis of time-variable networks, which was published in the Proceedings of the IRE in 1949. (The IRE became later the IEEE). A key concept in the thesis was that of a time-varying transfer function, which achieved great importance in the analysis of linear time-varying systems. A generalization of Wiener's theory of prediction was done one year later in a joint work with John R. Ragazzini. This work has found many applications to the design of finite- memory filters and predictors. People working in sampled-data are used to applying the z-transform, but most text books however forget to mention that in the early 50's, Zadeh and Ragazzini did pioneering work on the development of the z-transform approach to the analysis of sampled-data systems. Most of his teaching and research experience finally led to the publication, coauthored with Charles Desoer, of the (now classic) textbook on the "State-Space Theory of Linear Systems". This book is considered to be a keystone in the development of the state-space approach and its application to optimal control and system analysis. At this point of his career, Zadeh was already full professor at UC-Berkeley and well known and respected in the automatic control and system theory communities.

The decade of 1960 was that during which man reached the Moon. The success of the "Man on the Moon" project was seen as a triumph of precision. This, and the fact that a man who had seriously been engaged in the classical system theory would start not only advocating acceptance and recognition of the value of imprecision, but also proposing its formal treatment, may possibly partially explain the big controversy that followed the publication of Zadeh's seminal paper "Fuzzy Sets" in *Information and Control* in 1965. However, later the indisputable industrial success of fuzzy logic applied to control (as in the case of the subway train of Sendai, Japan, to recall one of the earliest and best known ones) dissipated all possible remaining doubts.

An interest in new subjects is one of Zadeh's unchanging characteristics. In 1950, he published two articles, "Machines that think: A new field of Electrical Engineering" and "An extension of the Wiener theory of prediction", which could be considered, respectively, forerunners of Artificial Intelligence and Systems Theory; a term that he first coined in another article published in the Columbia Students Magazine in 1954. During that period, he spent some time at the Institute for Advanced Studies, Princeton, where he was the only engineer among famous mathematicians and physicists. As far as he was concerned, these were "fantastic but enormously naive years", and "everything seemed possible".

In 1959, he moved to Berkeley University in California where he lectured again on new subjects, such as "Finite State Machines" and "Linear Systems Theory", which was to be his speciality for years, and to which he had made important contributions, especially in an understanding of state spaces.

Whilst studying Linear Systems, he concluded that "formal precision had its limits, and that the formalization of Linear Systems could not go beyond a certain level of rigorous precision, which, once surpassed, rendered conclusions of little relevance". Thus, in his 1961 paper "From the Theory of Systems to the Theory of Circuits", he expressed the need of a tool to deal with situations he called "fuzzy", using this term for the very first time, although not in the more specific sense that he would later attach to it.

From 1963 to 1968, he was Head of Berkeley's Computer Science Department; these were difficult and troubled years in which this task absorbed him completely, having to deal with "political battles including some quite unpleasant ones, since the very existence of the Department was at stake".

In the summer of 1964, he spent a week at the Rank Corporation and the idea of fuzzy set emerged as simple and attractive for him. As a matter of fact, he had been concerned for many years with the problem of classifying objects according to roughly precise categories, as well as on the imprecise frontiers between the resulting classes. He wrote a report for the Rand

Corporation, and later publicly expanded the idea in a lecture given at Berkeley in the Autumn of 1964. After some set-backs, he published the famous 1965 paper "Fuzzy Sets" in *Information and Control*. This article today is one of the citation classics, possibly, an epoch-making article.

At the end of his period as Head of the Computer Sciences Department, he took sabbatical leave at M.I.T., and there he wrote the important article "Probability Measures of Fuzzy Events" (1968), which opened up several fields of research. He also attempted to apply his ideas to the theory of Systems and Algorithms, e.g. in "Fuzzy Algorithms" (1968) and in "Toward a Theory of Fuzzy Systems" (1971), eventually concluding that all the problems generated by fuzzy sets were, in the last analysis, problems of linguistics.

During a mathematics convention held in Moscow in 1966 and in a lecture given in Paris in 1979, he dealt with fuzzy language and its relation to human and artificial intelligence. These lectures provide a vital landmark for an understanding of the evolution of Zadeh's subsequent thoughts. In the same direction, we may consider the following articles as milestones on the way to Computing with Words:

- "Quantitative Fuzzy Semantics" (1971).
- "A Fuzzy Set theoretic interpretation of Linguistic Hedges" (1972).
- "The concept of Linguistic Variable and its applications to Approximate Reasoning" (1975, but prepared in 1973 during another period at M.I.T.).
- "Calculus of Fuzzy Restrictions" (1975).
- "Fuzzy Sets as a basis for a Theory of Possibility" (1978, the first paper in the first issue of the Journal *Fuzzy Sets and Systems*).
- "PRUF — A meaning representation for Natural Languages" (1978).
- "Test-Score Semantics for Natural Languages and Meaning representation *via* PRUF" (1981, prepared during a visit to SRI International).

After those papers, Zadeh made interesting contributions to the new fields of Approximate Reasoning and Expert Systems. I would recall, particularly, the article he published in 1977 with the late Richard Bellman: "Local and Fuzzy Logics", and also:

- "A Theory of Approximate Reasoning" (1979).
- "The role of Fuzzy Logic in the Management of Uncertainty in Expert Systems" (1983).
- "A Computational approach to Fuzzy Quantifiers in Natural Languages" (1983).
- "A Theory of Commonsense Knowledge" (1984).
- "Syllogistic Reasoning in Fuzzy Logic and its applications to Reasoning with Dispositions" (1985).
- "Outline of a computational approach to meaning and knowledge representation based on a concept of a generalized assignment statement" (1986).
- "A computational theory of dispositions" (1987).
- "Dispositional Logic" (1988).
- "Qualitative systems analysis based on fuzzy logic" (1989).
- "Fuzzy Logic and the Calculus of Fuzzy If-Then Rules" (1991).

As an indication of his line of thought, I might quote the following from the above-mentioned article with R. Bellman: "Although Fuzzy Logic represents a significant departure from conventional approaches to the formalization of human reasoning, it constitutes – so far at least – an extension rather that a total abandonment of the currently held views on meaning, truth and inference". Zadeh has introduced "flexibility" in Logic, and his celebrated *Compositional Rule of Inference* is, jointly with his modeling of Fuzzy Syllogisms, a point of departure for a new consideration of reasoning with imprecise predicates, as in commonsense reasoning. Fuzzy Logic introduced by Zadeh is a flexible logic to deal with calculus with imprecise predicates on classical universes of discourse, because in Zadeh's view, a large part of human reasoning is concerned with problems "…in which the source of imprecision is the absence of sharply defined criteria of class membership rather than the presence of random variables".

That idea is particularly important in the context of trying to develop machines that think like people, simulating "the remarkable human ability to attain imprecisely defined goals in a fuzzy environment". An important tool was, in that direction, the treatment of Fuzzy Quantifiers as Fuzzy Numbers, which can be manipulated using the rules of Fuzzy Arithmetic.

3. Elasticity

Perhaps, "Is a matter of degree" is the most frequent affirmation we listened or read from Zadeh. Let me discuss this for a while from an elementary logical point of view.

Classical logic is basically inelastic. Given a predicate, P, on a set of objects, X, the statements "x is P", if intentionally meaningful, are only true or false. This means that the linguistic relation attributing to each x in X the property expressed by P is the set of couples: $L = \{(x, P); x \in X\}$, and the extensional *meaning* of P in X : $\mathbf{P} = \{x \in X; (x, P) \in L\}$ exists, which in its turn, is also a subset of X. Zadeh's ideas on Logic are rooted in *elasticity*, because in ordinary life, the situation is not so crisp as in classical logic. If $P =$ BIG and X is the unit interval $[0, 1]$ the statements "1 is BIG" and "0 is BIG" are, respectively, true and false, but what to say regarding "0.5 is BIG"? Clearly, with a predicate of such common use as BIG, there are statements "x is P" that remain unclassified under the criterion given by (true, false). Such predicates appear very often in usual discourse, because they are very informative; common sense reasoning is elastic, although this elasticity could easily produce inconsistencies.

Zadeh considered that between P and each x exists some degree of compatibility, that L is a function assigning to each couple (x, P) a member of some set (for example, of numbers or of linguistic terms) giving such a degree. Then, the *extensional meaning* of P is no longer viewed as a set but as a function $\mu p(x) = L(x, P)$ for each x in X. In my view, to give extensionality to predicates like BIG is an important contribution to Logic.

Predicates P on set X, such that X is perfectly classified in two classes: $\mathbf{P}$ (the extensional meaning of P on X) and $\mathbf{P}'$ (its complementary subset), which are called Classical, Crisp or Fregean predicates. When such partition is not possible, we speak of *Imprecise, Vague* or *Fuzzy Predicates*, and they are characterized by the existence of the set:

$\{x \in X$; "x is P" is neither true nor false$\}$,

of elements to which P applies but not completely.

Following Tarski's ideas on truth, "x is P" is true if it is the case that x is P, and x satisfies completely P. Then with vague predicates, we are confronted with cases in which some x partially satisfies P. Two questions are to be considered: the possibility of measuring such extent and, if it is possible, to express it by elements of some set.

Zadeh's work is mainly under the hypothesis of measurability on the unit interval: $L(x, P) = \mu_P(x)$ is in $[0, 1]$. Then $L(x, P)$ is the degree to which x satisfies P, or is compatible with P, and

Zadeh hypothesized the existence of a new entity, **P**, the fuzzy subset of X with name or linguistic label, P. Such an object is characterized by the compatibility function of P, that now is called the *membership function* of **P**, and it is individuated by the 'equality',

$$\mathbf{P} = \mathbf{Q} \quad \text{iff} \quad \mu_P = \mu_Q.$$

Of course, when P is a classical predicate, then:

$$\mu_P = \chi_P,$$

the membership function is the characteristic function of the extensional meaning of the classical predicate under consideration. In that sense, Zadeh's theory contains the classical theory of subsets of X, and a fuzzy set can be viewed as the extensional meaning of an imprecise predicate on X.

As a consequence of such a model, it is possible to give an interesting definition concerning the use of linguistic modifiers. For each group, G, of transformations in $[0, 1]^X$, we have the equivalence;

$$\mathbf{P} = \mathbf{Q} \quad \text{iff} \quad \mu_Q = g(\mu_P), \quad \text{for some } g \in G,$$

which we can read as "Q is a G-modified of P" and, if G is reduced to the identity, we get just the logical equivalence $(*)$.

For example, if $J(x) = x$, the group $G = \{J, J^2, J^{\frac{1}{2}}\}$ gives an important family of modifiers:

- If $\mu_Q = J^2(\mu_P) = \mu_P^2$, it is said that Q is the predicate VERY P;
- If $\mu_Q = j^{\frac{1}{2}}(\mu_P) = \mu_P^{\frac{1}{2}}$, it is said that Q is the predicate MORE OR LESS P;

both of great importance in Fuzzy Logic. Also the group $G = \{J, 1 - J\}$ gives a well known modifier: If $\mu_Q = 1 - \mu_P$, and it is said that Q is the predicate, NOT P.

If G is chosen to substitute predicates, *salva veritate*, as a group of automorphisms of $[0, 1]^X$ related to the connectives used among the predicates, then we get a definition of synonymy, or more precisely of G-synonymy. Nevertheless, as synonymy is not a transitive relation, it is more realistic to take a family of automorphisms not-closed by composition.

All this is a mere illustration of the interesting possibilities that Zadeh opened for Linguistics.

But as Zadeh's real interest was on systems which behavior could be linguistically described, he went on to the very interesting idea of linguistically interpreting the truth by introducing the Linguistic Variable *TRUTH*, whose values are:

{TRUE, FALSE, NOT TRUE, NOT FALSE,
VERY TRUE, VERY FALSE, ...}.

Zadeh considered such values of *TRUTH* as imprecise predicates on the unit interval [0, 1], represented by the corresponding fuzzy sets through its membership functions. For example:

$\mu_{\text{TRUE}}(x) =$ Degree of compatibility of the predicate TRUE with the number x considered as a possible truth value of some statement.

Of course, $\mu_{\text{TRUE}}(0) = 0$, $\mu_{\text{TRUE}}(1) = 1$ and obviously if $x < y$, then $\mu_{\text{TRUE}}(x) < \mu_{\text{TRUE}}(y)$. Zadeh selected the easier solution $\mu_{\text{TRUE}}(x) = x$ in some sense the average solution. Analogously, Zadeh defined the antonym:

$$\mu_{\text{FALSE}}(x) = \mu_{\text{TRUE}}(1 - x) = 1 - x,$$

and, then:

$$\mu_{\text{VERY TRUE}}(x) = x^2,$$
$$\mu_{\text{VERY FALSE}}(x) = (1 - x)^2,$$
$$\mu_{\text{MORE OR LESS TRUE}}(x) = x^{\frac{1}{2}},$$
$$\mu_{\text{MORE OR LESS FALSE}}(x) = (1 - x)^{\frac{1}{2}}.$$

Fuzzy logic is the logic in which statements, "x is P", have as *Truth*-Values, the values of *TRUTH* described by the former compatibility functions, that is by those fuzzy sets in [0, 1].

Of course, given a *Truth*-Qualified statement like "x is P" is VERY TRUE, it is easy to compute its numerical *Truth*-Value by:

$$\mu_{\text{VERY TRUE}}(\mu_P(x)) = (\mu_P(x))^2.$$

In this apparently soft way, a powerful tool to manage linguistically described systems arises. What Zadeh did was to create an actual Predicate Calculus, useful to be applied both to the representation of common sense knowledge and to make inferences, like what people do in ordinary thinking on processes with imprecision.

4. Approximate deduction

There is no Logic without inference and the principal rule of inference is *Modus Ponens*. After Zadeh, we write such a rule as an equation and that is, at least historically, a new acquisition for Logic. To make inferences, Zadeh always considered the implication as a Fuzzy Relation, that is as the compatibility function of a binary predicate "If P, then Q"; and one of the major contributions of Lotfi Zadeh is, from the logical point of view and despite some initial shortcomings, the well known FUZZY MODUS PONENS or COMPOSITIONAL RULE OF INFERENCE.

The scheme of inference:

Rule	If "x is P", then "y is Q"
Observation	"x is P^*"
Conclusion	"y is Q^*"

typical of linguistically described systems was translated by Zadeh as follows:

- A Fuzzy Relation $R_{Q/P}(y/x)$ describing the conditionality expressed by the rule,
- A Fuzzy value $\mu_{P^*}(x)$ representing P^* and the degree on which x is P^*, the observation, and by the definition:

  $$\mu_{Q^*}(y) = \text{Sup}_{x \in X} T_0(\mu_{P^*}(x), R_{Q/P}(y/x)) \quad \text{for each } y \text{ in } X,$$

  for the conclusion, with a continuous t-norm T_0, with which, when $P^* = P$, it is $Q^* = Q$.

Such Modus Ponens not only contains, as a particular case, the classical Modus Ponens, but the transformation, $\mu_{P^*} \to \mu_{Q^*}$, enjoys the three properties of a Consequences Operator in Tarki's sense. This allows one to consider Q^* as a logical consequence of P^* following the given rule.

It may be that, in the deepest logical sense, what emerges from fuzzy logic is that concerning commonsense reasoning, Logic appears like Geometry after Gauss. Locally we manage a particular kind of logic adapted to what we actually know, and when moving from a piece of discourse to another, logic changes.

Even more, a new view of the same concepts of proposition or statement arises from Zadeh's work. A proposition "x is P" is *Truth*-Qualified, taking the corresponding value of the variable

TRUTH, depending on what is stored in a knowledge base. A proposition is qualified as *TRUE*, or *VERY TRUE*,…,depending on reasonable comparisons we are able to make, with what we know about it, in a similar framework to that in which the given proposition is inscribed. Tarski's *adequation to things* is now a function of what we actually know about things. It seems to be a realistic philosophical view, and it is also a very important fact that Zadeh constructed an algorithm to represent the principal linguistic terms appearing in a complex proposition; logically separable in minimal or atomic propositions.

Zadeh not only introduced the concept of fuzzy sets, but also a methodology for the representation of commonsense knowledge using fuzzy sets, and a way of making inferences with such knowledge once represented. He established the grounds for a coherent logic of commonsense reasoning, to such an extent that Approximate Reasoning and Fuzzy Logic are almost interchangeable terms.

If Boole made great advances by mathematizing an important part of exact reasoning, translating its pieces of discourse into mathematical equations solved with a especial calculus; if Pólya made great advances in the modeling of Plausible Reasoning by means of Probability Theory, then Zadeh made great advances by functionally modeling an important part of inexact reasoning that at the end is our typical kind of reasoning with which we argue every day on everything. At least, if Boole modelled the exact syllogism, Zadeh began the modeling of the approximate syllogism.

5. As a summary

The enormous growth of what has been called *Fuzzy Engineering* and *Fuzzy Technologies* could not have happened without the work of Zadeh. Rarely, in the history of Science and Technology, has the founder of a theory had such a direct influence on the technological and industrial success of applied ideas coming from the theory, as is the case with Zadeh. Zadeh has been a member of the U.S. Academy of Engineering since 1973, has lectured in many countries and has been awarded with several medals and Honorary Degrees. He is a man who "tends, by nature, to associate with all kinds of people" and, as a teacher he possesses a special air for presenting problems from an interesting angle and looking at them in an entirely new way.

Lotfi Zadeh is no mere scientist; he is a contemporary thinker whose sphere of action encompasses matters of relevance to the current evolution of our society, as, for example, his ideas on the present "crisis of undercoordination", that he roots both in the constant growth of the degree of interaction and interdependence in all strata of modern societies, and in some lack of leadership. If I were to summarize Zadeh's work, I would do so, using the following seven points:

1. Zadeh broke an old frontier of knowledge with the introduction of fuzzy sets, fuzzy logic and Soft Computing. Namely, a frontier consisting of only looking at computer technology though the glasses of bivalent logic.
2. Thanks to the work of Zadeh, true progress on computation with imprecise concepts took place from 1965 to the end of the 20th Century. For instance, at that time, Fuzzy Control achieved an impressive success in both theoretical and applied sides. To quote just a few examples of applications; the automatic drive of metropolitan trains, the automatic functioning of water potabilization plants, a lot of market appliances, ranging from 'intelligent' washing machines, camcorders or photographic cameras to tensiometers, and expert systems for diagnostics are among the most well known appliances and come from the paradigm of controlling an inverted pendulum through expert linguistic rules describing its behavior. In this respect, the last success is the perfect control of an inverted pendulum with three articulations, something that is extremely difficult for humans.
3. Zadeh is the person mainly responsible for the success of Fuzzy Control using two basic theoretic contributions, the so-called Generalized Modus Ponens Scheme for imprecise reasoning, and the Compositional Rule of Fuzzy Inference that gives the algorithm's output, as well as the definition of Linguistic Variables and the ways of representing and computing with them. Both contributions are today in the armamentarium of any fuzzy logic practitioner.
4. Zadeh is at the absolute top of citations. His publications that, with the exception of a few, are signed only by himself, excited a lot of researchers around the world to work in the fields of Fuzzy Logic and Soft Computing, from either a theoretic or applicative perspective. The world community of people doing research in these fields is constituted by an amalgam of engineers, computer scientists, physicists, mathematicians, etc. It is actually an interdisciplinary community.
5. In the last decade of the 20th Century, Zadeh introduced a new paradigm in the field of Computation with his concept of Soft Computing as a hybridization of methodologies coming from Fuzzy Logic, Neural Networks, Evolutionary Algorithms, and Probabilistic Reasoning. Today, around twenty years after its inception, the field of Soft Computing is not only the most productive area in Computational Intelligence, but the methodology allowing information technology corporations to design processes and products with a true reduction of costs. Zadeh's idea on Soft Computing transformed methodologies that were in competition into cooperative methodologies able to manage, thanks to the core methodology of fuzzy logic, linguistic descriptions of system behaviors. Today, and following Zadeh's recent ideas, Fuzzy Logic is evolving towards Computation in Natural Language, that is towards the actual challenge of Computational Intelligence.
6. A close look at Zadeh's CV shows that he is not only a theoretical electronic engineer specialized in Computer Science, but a thinker that contributed to shedding light on how to change or improve old fashioned ways of working in Systems Theory, Control Theory, Artificial Intelligence, and also, some aspects of the Philosophy of Vagueness. For instance, Zadeh is referred to in many books concerning the Philosophy of Vagueness, and also in those concerning the history of Cybernetics, Control and Systems Theory.
7. A last, but not least, important aspect of Zadeh's life is his way of confronting criticism. Not only did he never avoid criticism of his work, but always encouraged people to criticize his idea; and he did it in a very polite and gentle form. It should be recalled that since Zadeh's first ideas on fuzzy logic fell down the wall of crisp bivalent logic and the mystics of precision, by introducing contextual and purpose driven representations of imprecise concepts, he received strong criticism coming from prestigious researchers. Nevertheless, forty years later, it can be said that Zadeh's ideas not only resisted criticism but imposed on them.

6. Conclusion

Let me finish by reflecting a little on a problem that, to my knowledge, is again an important open question. It was the

French mathematician, Henri Poincaré, one of the recognized wise men of the last century, who differentiated the physical continuum by the appearance of non-transitive relations:

$$a = b \quad \text{and} \quad b = c, \quad \text{but } a \neq c.$$

Later, Menger tried to use his Probabilistic Relations to model the Poincarfie paradox, evidently close to the Sorites paradox. Thanks to the pioneering ideas of Zadeh, and after the use of t-norms and t-conorms for the *AND*, *OR* connectives, respectively, we have today the concept of Indistinguishability Relations with which not only a window was opened in the analysis of concrete cases in which the Poincaré's paradox appears, as is the case for synonymy, but also the possibility of obtaining the logic we work with when knowing an imperfect classification and the Indistinguishability has, as generator, an Implication's Relation. That line of research can, in my opinion, be a real tool for the understanding of many phenomena, not only in the field of Approximate Reasoning but also in other fields of Science.

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The paper is, furthermore, on some aspects on the life of Professor Lotfi Zadeh and has been written by simple memory of the author; therefore the references are only to suggest the readers something interesting to read.

Further reading

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